

# THE XMM-NEWTON SSC SURVEY OF THE GALACTIC PLANE

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## ABSTRACT

The XMM-Newton Survey Science Center is currently conducting an optical identification programme of serendipitous EPIC sources at low galactic latitudes. The aim of this study is to quantify the various populations contributing to the overall X-ray emission of the Galaxy and elaborate identification rules that can be later applied to the bulk of the low galactic latitude EPIC detections. We report here on preliminary results from an optical campaign performed in two very low  $b$  XMM-Newton fields and discuss the contributions of the various X-ray populations. This paper is presented on behalf of the Survey Science Center and of the AXIS collaboration.

Key words: Missions: XMM-Newton – Surveys: X-ray — Stars: Active Coronae

## 1. INTRODUCTION

One of the most challenging responsibilities of the Survey Science Center (SSC) of the XMM-Newton satellite is to characterise, in a proper fashion, the  $\sim 50,000$  new EPIC sources discovered every year. In order to cope with this task, the SSC has designed a strategy based on the concept of 'statistical identification'. Four samples of about 1000 EPIC sources are the scope of optical observing campaigns aiming at a complete spectroscopic identification. In parallel, multi-colour wide field imaging is carried out on a large number of XMM-Newton fields. The correlations existing between the nature of the identified sources and their X-ray and optical photometric characteristics will then be used to identify in a statistical manner the rest of the XMM-Newton EPIC sources. At high galactic latitude, three spectroscopic samples with limiting sensitivities of  $10^{-15}$ ,  $10^{-14}$  and  $10^{-13}$  erg cm $^{-2}$  s $^{-1}$  in the 0.5-4.5 keV energy range are currently under investigation. First results from the medium and bright sensitivity samples are discussed in Barcons et al. (2002) and Della Ceca et al. (2002) and the overall role of the SSC and supporting optical observations are described in Watson et al. (2001).

We report here on the status of the identification programme carried out on the fourth sample located at low

galactic latitude ( $|b| \leq 20^\circ$ ), the XMM-Newton SSC survey of the galactic plane (see Motch (2001)). Many individual source types contribute to the X-ray population of our Galaxy. These include late and early-type stars, RS CVn's, cataclysmic variables (CVs), X-ray binaries, distant star forming regions and supernovae remnants. Other more exotic X-ray emitters such as isolated neutron stars might also show up. By separating these populations and eliminating the contamination due to background AGN, we can hope to obtain a remarkable view of the accretion power, star formation and end-points of stellar evolution throughout the Galaxy.

## 2. X-RAY AND OPTICAL OBSERVATIONS

In this paper we describe preliminary results from EPIC pn observations of two fields belonging to the low galactic latitude sample. The first one, centered on the supernova remnant G21.5-0.9 was observed several times at different off-axis angles during the PV/Cal phases. The source list discussed here was constructed from the two deepest observations performed during revolutions 60 and 62. Usable EPIC pn + medium filter times are 19 ksec and 23.5 ksec respectively. The source search was performed on individual pointing data and later merged into a single master list. The second field, Ridge 3, is located less than 2 deg away and is slightly less deep with an EPIC exposure time of only  $\sim 9.5$  ksec. We list in Table 1 the main properties of the two target areas.

In order to be sensitive to the large variety of X-ray spectra exhibited by low latitude sources both galactic and extragalactic, all detections made in the 0.5-2.0 keV, 2.0-4.5 keV, 4.5-7.5 keV and 7.5-12 keV bands were retained for optical identification. Source lists were manually screened to reject false detections. In one field, G21.5-0.9, the positions derived from the satellite attitude control system were further refined using sets of soft X-ray sources identified with optically bright objects, presumably active coronae. Up to 4'' offsets were applied, consistent with those found in high galactic latitude pointings (Watson et al. 2001).

Optical observations were made using telescope time allocated to the AXIS project which forms the backbone of the SSC identification programme (Barcons et al. 2002).

In addition, some wide-field imaging data have been collected with the ESO-MPG 2.2m at La Silla. AXIS uses the largest telescopes of the Observatorio del Roque de los Muchachos (Isaac Newton Telescope, Nordic Optical Telescope, Telescopio Nazionale Galileo and William Herschel Telescope). Wide field u,g',r',i' and in some cases also infra-red imaging were collected at the INT. Medium to low resolution spectroscopy was obtained with the NOT, TNG and WHT telescopes using the ALFOSC, DOLORES, WYFFOS and ISIS instruments.

Table 1. Galactic XMM-Newton target fields

Field	RA (J2000)	Dec	$l$	$b$	No. of sources	Area (deg <sup>2</sup> )
G21.5-0.9	18h33	-10° 34'	21.5°	-0.9°	70	0.27
Ridge 3	18h27	-11° 29'	20.0°	+0.0°	21	0.18

### 3. OPTICAL IDENTIFICATIONS

The main criterion for identifying an X-ray source with an active corona is the presence of Balmer and Ca II H&K emission which are the commonly accepted signature of chromospheric and hence coronal activity. Active M stars display easily detectable Balmer emission lines even at relatively low signal to noise ratios. For solar type stars, Balmer emission may not be detectable because of the underlying photospheric absorption and at the moderate spectral resolution of 3 to 10 Å used in our optical identification work the Ca II H&K emission may have a too low contrast to be revealed in stars earlier than about G-K. Therefore, part of the stellar identifications have to rely on the low probability to find an optically bright object in the small EPIC error circle. In order to compute this probability we used our R band imaging data and GSC 2.2 extractions to derive magnitudes for the brightest optical objects in the 90% confidence error circle as well as cumulative stellar densities versus magnitudes. At the 95% confidence level we estimate that any star located in the 90% error circle and brighter than  $R \sim 17$  and  $R \sim 16.8$  is a likely counterpart for the G21.5-0.9 and Ridge 3 fields respectively. The mean error on source position was about 2'' for these two fields.

The current statistics of optical identifications is shown in Table 2. The accreting source close to G21.5-0.9 is the likely Be/X-ray binary SS 397 while the extragalactic source is the cluster XMMU J183225.4-103645 whose nature has been determined on the basis of XMM-Newton data alone ( $z = 0.1242$ , Nevalainen et al. 2001). We estimate that we are optically complete down to  $R \sim 19$  for emission line objects.

Among the 27 active coronae are 8 Me stars. Most of them are fainter than  $R = 19$ , the faintest one being  $R = 20.8$ . Fig. 1 shows that the ratio of their X-ray to  $H\alpha$  flux is very similar to those of Me stars detected in low galac-

Table 2. Statistics of optical identifications

Field	G21.5-0.9	Ridge 3
Total	70	21
Stellar Coronae	16 (23%)	11 (52%)
Accreting	1	0
Extragalactic	1	0
Unidentified	52 (74%)	10 (48%)

tic latitude ROSAT surveys (Motch et al. 1997). So far, most of them fall in the same spectral range (earlier than about M5) and the same X-ray luminosity range ( $L_X \sim 10^{29-30} \text{ erg s}^{-1}$ ) as ROSAT detections. This indicates that the Me star population detected by XMM-Newton is not much different from that seen in the ROSAT survey and located roughly ten times farther away. The fraction of Me stars among XMM-Newton active coronae ( $\sim 30\%$ ) may be slightly larger than that seen in the low latitude ROSAT survey ( $\sim 19\%$ , Motch et al. 1997). Note, however, that the actual ratio may be somewhat different since stellar identifications are certainly not yet complete.

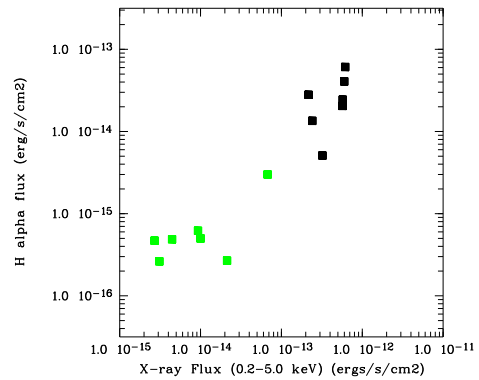


Figure 1.  $H\alpha$  versus X-ray flux for Me stars. In green; Me stars identified in the two XMM-Newton fields. In black; Me stars in the Cygnus area of the ROSAT galactic plane survey. ROSAT to XMM-Newton flux conversion factor was derived assuming a thin thermal spectrum with  $kT = 0.86 \text{ keV}$  and  $N_H = 5 \cdot 10^{20} \text{ cm}^{-2}$ .

EPIC pn sources identified with active coronae display significantly softer HR2 than the rest of the population (see Fig. 2). We use here the same definition as in pipeline processing, i.e.;

$$\text{HR2} = \frac{C(2.0-4.5) - C(0.5-2.0)}{C(2.0-4.5) + C(0.5-2.0)}$$

where  $C(A-B)$  is the EPIC pn count rate in the A to B keV range. Our mean stellar HR2 is harder than that reported by Della Ceca et al. (2002) ( $\text{HR2} \leq -0.8$ ). Two

cooperating effects could account for harder coronal spectra in low  $b$  samples. First, the larger distances result in larger interstellar absorption toward the sources. Second, stellar X-ray count models (Favata et al. 1992, Guillout et al. 1996) predict that a population of very young stars with small scale height or a population of very active binaries (RS CVn's) may dominate stellar identifications in low latitude X-ray surveys. In contrast, the high latitude population is expected to be mostly made of older and less X-ray luminous stars. Therefore the overall correlation between X-ray luminosity and temperature (see e.g. Schmitt 1997) could also explain the harder stellar X-ray spectra seen in our sample.

The good correlation between HR2 and stellar nature gives us confidence in the criteria applied and opens good prospects for setting up an automated identification procedure for relatively bright active stars.

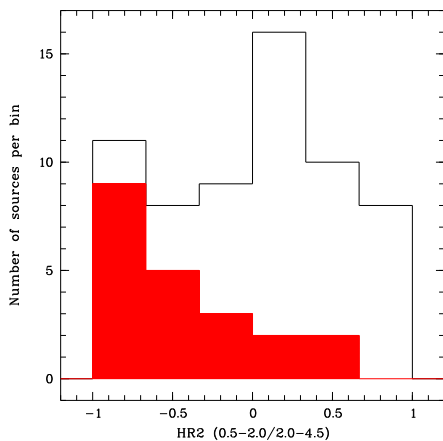


Figure 2. HR2 distribution of all sources in the two fields. The red histogram represents the distribution of X-ray sources identified with active coronae.

#### 4. THE EXTRAGALACTIC SOURCE BACKGROUND

The sensitivity of XMM-Newton above a few keV allows the extragalactic source background to be detected throughout the whole Galaxy, even in the presence of relatively high interstellar absorption. A good example of this 'contamination' is the discovery of an X-ray bright cluster of galaxies (XMMU J183225.4-103645) in the field of G21.5-0.9 (Nevalainen et al. 2001). Since the bulk of the photoelectric absorption ( $N_H = 7.9 \pm 0.5 \cdot 10^{22} \text{ cm}^{-2}$ ) from the cluster is of interstellar origin we can use it as a calibrator to estimate the range of integrated galactic  $N_H$  in the two fields. The fact that the value of  $N_{HI} \sim 2 \cdot 10^{22} \text{ cm}^{-2}$  (Dickey & Lockman 1990) is much lower suggests that in these directions most of the photoelectric absorption comes from the cold and dense phase of the ISM. The CO intensity at the cluster location taken from

the map of Dame et al. (2001) (0.25 deg spatial resolution) then yields a  $N_{H2}$  to CO intensity conversion factor of  $2.7 \pm 0.4 \cdot 10^{20} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$ . This value is slightly above that derived at  $|b| \geq 5^\circ$  by Dame et al. (2001) ( $1.8 \pm 0.3 \cdot 10^{20} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$ ) but consistent with or below those listed in Solomon & Rivolo (1986). This 'local' calibration and the CO velocity integrated map yield a total galactic  $N_H$  in the range of 5 to  $9 \cdot 10^{22} \text{ cm}^{-2}$  and 6.5 to  $11.6 \cdot 10^{22} \text{ cm}^{-2}$  for the G21.5-0.9 and Ridge 3 areas respectively. The infrared dust map of Schlegel et al. (2001) provides very similar values.

We show in Fig. 3  $\log N(>S)$ - $\log S$  curves for the G21.5-0.9 field together with the extragalactic ASCA number count relations (Ueda et al. 1999) extrapolated to faint fluxes. Energy to count factors were computed for the EPIC pn + medium filter assuming a power law spectrum with photon index 1.9 representative of AGN energy distributions and a range of  $N_H$  of a few  $10^{22} \text{ cm}^{-2}$ . Note that for the same count rate, a much softer energy distribution such as that emitted by stellar coronae would imply a factor of  $\sim 5$  fainter X-ray flux in the 0.5-4.5 keV range. The  $\log N(>S)$ - $\log S$  curves have not been corrected for full coverage and completeness and are unreliable below  $\sim 2 \cdot 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$  (0.5-4.5 keV) and  $\sim 3 \cdot 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$  (4.5-7.5 keV).

In spite of possible inaccuracies in the various flux calibrations, it seems that at our flux completeness level, sources detected in the 0.5-4.5 keV range are not yet dominated by the extragalactic population (see Fig. 3 left panel). For the  $N_H$  range derived in the G21.5-0.9 field, the extragalactic component could at best account for  $\sim 10\%$  of the 0.5-4.5 keV sources at  $3 \cdot 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ . This conclusion is independently supported by the HR2 distribution (see Fig. 2) since only few sources display a HR2 harder than the minimum value of  $\sim 0.7$  expected for an AGN seen through  $N_H \geq 5 \cdot 10^{22} \text{ cm}^{-2}$ . Assuming that some sources with  $HR2 \geq 0.0$  are extragalactic ( $N_H \geq 2 \cdot 10^{22} \text{ cm}^{-2}$ ) raises the AGN contribution but not to a point where it can dominate the source content.

However, as suggested in Fig. 3, the very faint end of the 4.5-7.5 keV hard sources could well be dominated by the AGN background. A modest extragalactic background of sources in our XMM-Newton fields does not contradict the result recently reported by Ebisawa et al. (2001) based on deep Chandra observations of similar low latitude directions. The 2-10 keV energy range in which the extragalactic dominates over galactic source population is  $3 \cdot 10^{-15}$  to  $\sim 3 \cdot 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$  while our estimated completeness level in the same energy range is only a few  $10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ .

#### 5. CONCLUSIONS

In the present state of our work, the nature of the unidentified sources which still represent the majority of the cases remains unclear. Because of the patchiness of the cold in-

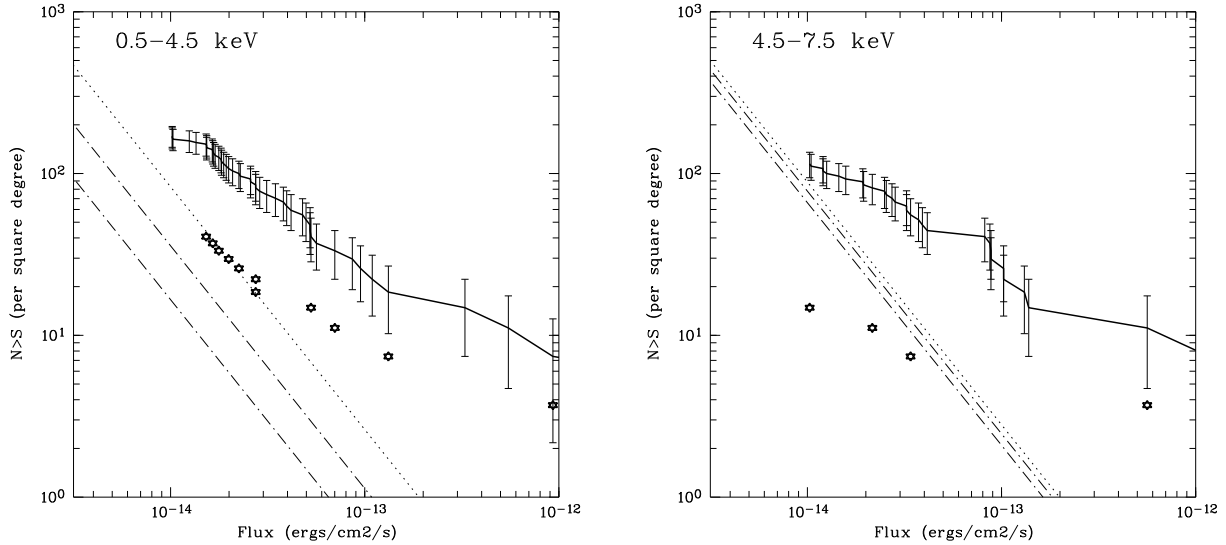


Figure 3. Left:  $\log N(>S)$ - $\log S$  (0.5-4.5 keV) curve for XMM-Newton sources in the G21.5-0.9 field (thick line) computed using an energy to count factor typical for background AGN. Stars represent the number count relation for active coronae. The extragalactic ASCA  $\log N(>S)$ - $\log S$  absorbed by  $N_H = 5$  and  $9 \times 10^{22} \text{ cm}^{-2}$ , the value suggested by HI and CO maps, are shown as long dashed lines while that computed assuming  $N_H = 2 \times 10^{22} \text{ cm}^{-2}$ , compatible with the HR2 distribution, is the dotted line. Right: Same figure in the 4.5 to 7.5 keV energy range

terstellar medium the density of background AGN may be slightly underestimated but apparently not to the point where it can dominate source counts. It is fairly possible that a large number of active coronae have escaped our investigations. We expect some EPIC sources to be identified with young active F-K stars or RS CVn binaries fainter than the  $R \sim 17$  limit set for chance position coincidence by the still relatively large error circles and high field stellar densities. Detecting the sometimes subtle signature of their X-ray activity, such as close binarity, filled  $H\alpha$  line or Ca II H&K emission may be very consuming in optical observing time. We may have also missed some of the optically faintest Me stars below  $R = 19$ . Part or all of the soft HR2 unidentified sources seen in Fig.2 could well be optically faint active coronae.

Cataclysmic variables may also contribute to some extent. They can exhibit a wide range of X-ray spectra and although their X-ray  $\log N(>S)$ - $\log S$  remains uncertain (Watson 1999) they could account for up to  $\sim 10$  of the 70 sources in the field of G21.5-0.9 while still being optically fainter than  $R \sim 19$ . Both Me stars and CVs are strong Balmer lines emitters and the deep narrow band  $H\alpha$  imaging currently carried out will provide strong constraints on the density of these populations.

The lower identification rate and stellar fraction in the G21.5-0.9 field compared to that of Ridge 3 is probably due to a nearby absorbing structure clearly visible on the DSS-2 images and reflected in the fact that at  $R = 16$  the cumulative density of stars in Ridge 3 is twice that of

G21.5-0.9. The local cloud in G21.5-0.9 could also account for the generally harder HR2 distribution in that field.

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